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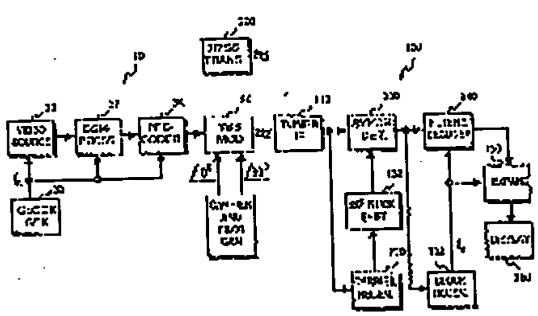
(54) VSB HDTV TRANSMISSION SYSTEM WITH REDUCED NTSC CO-CHANNEL INTERFERENCE

(54) SYSTEME DE TELEDIFFUSION HAUTE DEFINITION A BOITE DE COMMANDE VIDEO AVEC INTERFERENCE REDUITE SELON LA NORME NTSC

Representative Drawing:



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ABSTRACT:

A television signal transmission signal comprises a suppressed carrier, VSB signal having respective Nyquist slopes at the lower and upper edges of a 6MHz television channel, the center frequency of the Nyquist slope at the lower edge of the channel being substantially coincident with the frequency of the suppressed carrier, and the pilot signal in quadrature relation with the suppressed carrier. The suppressed carrier is modulated by an N-level digitally encoded signal having a sample rate fs substantially equal to three times the NTSC color subcarrier frequency, with the frequency of the color subcarrier being less than the co channel NTSC picture carrier by an amount equal to about fs/12. The received signal is

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(86) 1991/11/07
(87) 1992/05/10
(45) 1999/08/03

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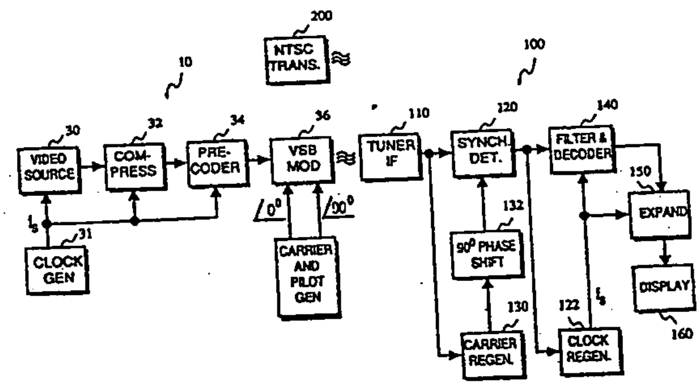
(30) 1990/11/09 (611,236) US

(54) **SYSTEME DE TELEDIFFUSION HAUTE DEFINITION A BOITE DE COMMANDE VIDEO AVEC INTERFERENCE REDUITE SELON LA NORME NTSC**

(54) **VSB HDTV TRANSMISSION SYSTEM WITH REDUCED NTSC CO-CHANNEL INTERFERENCE**




(57) Signal de transmission de signaux de télévision comprenant une porteuse supprimée, un signal BLR ayant des pentes de Nyquist respectives sur les bords inférieur et supérieur d'un canal de télévision de 6MHz, la fréquence centrale de la pente de Nyquist sur le bord inférieur du canal coïncidant pratiquement avec la fréquence de la porteuse supprimée, et un signal pilote en relation de quadrature avec la porteuse supprimée. La porteuse supprimée est modulée par un signal codé numériquement de niveau N ayant un rythme d'échantillonnage fs pratiquement égal à trois fois la fréquence de la sous-porteuse couleur NTSC, la

(57) A television signal transmission signal comprises a suppressed carrier, VSB signal having respective Nyquist slopes at the lower and upper edges of a 6MHz television channel, the center frequency of the Nyquist slope at the lower edge of the channel being substantially coincident with the frequency of the suppressed carrier, and the pilot signal in quadrature relation with the suppressed carrier. The suppressed carrier is modulated by an N-level digitally encoded signal having a sample rate fs substantially equal to three times the NTSC color subcarrier frequency, with the frequency of the color subcarrier being less than the

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(87) 1992/05/10
(45) 1999/08/03

fréquence de la sous-porteuse couleur étant inférieure d'une valeur égale à environ fs/12 à la porteuse d'image NTSC dans un même canal. Le signal reçu est démodulé par un détecteur synchrone en réponse au signal pilote reçu et les éléments de battement NTSC parasites sont atténués par un filtre linéaire produisant des flancs raides à fs/12, 5fs/12 et fs/2. La sortie du filtre comprend un signal de niveau M, M étant supérieur à N, qui est converti en un signal de sortie de niveau N représentant l'image télévisée.

co-channel NTSC picture carrier by an amount equal to about fs/12. The received signal is demodulated by a synchronous detector in response to the received pilot signal and interfering NTSC beat components are attenuated by a linear filter having notches at fs/12, 5fs/12 and fs/2. The output of the filter comprises an M-level signal, where M = greater than N, which is converted to a N-level output signal representing the televised image.

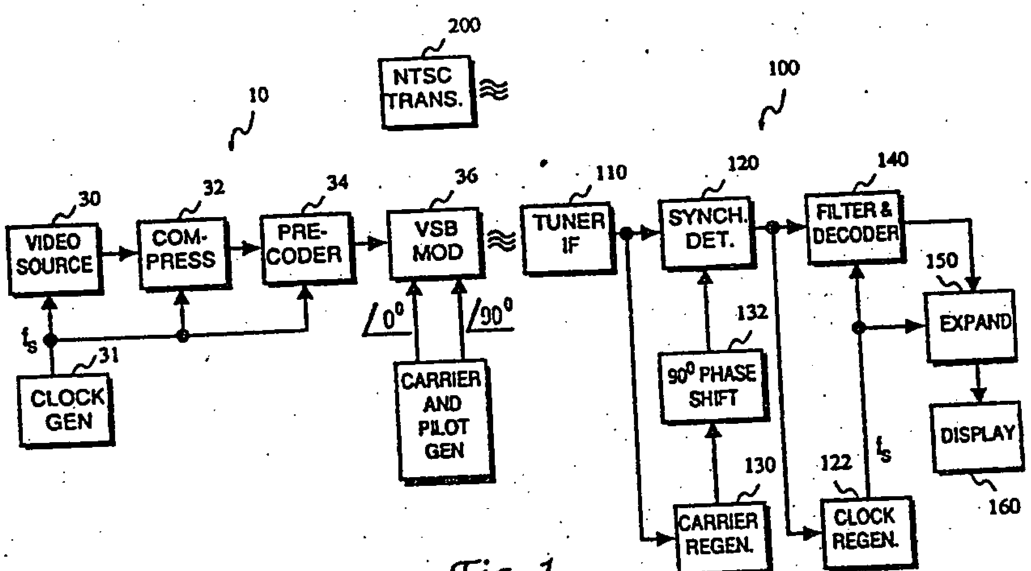


*Fig. 1*

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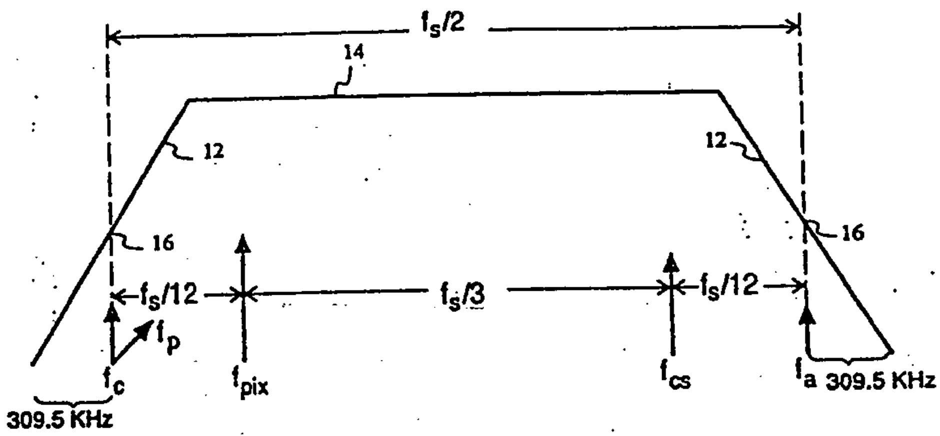


Fig. 2

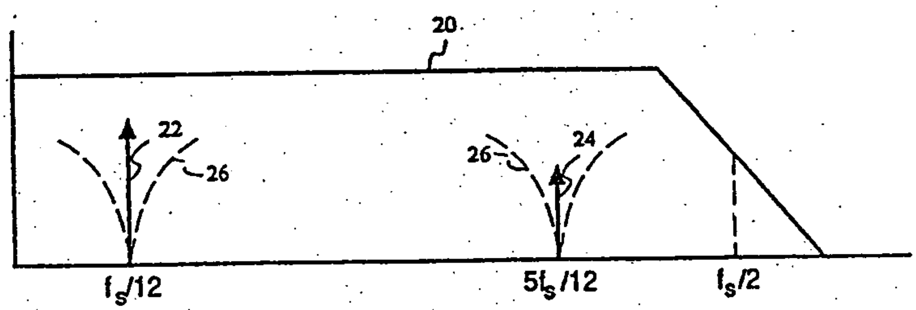


Fig.3

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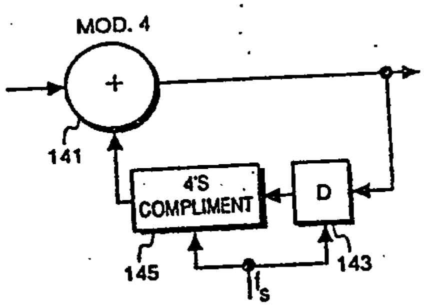


Fig. 4A

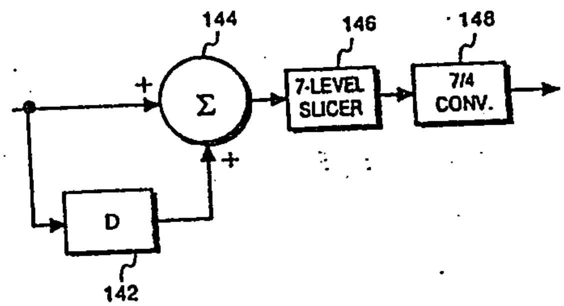


Fig. 4B

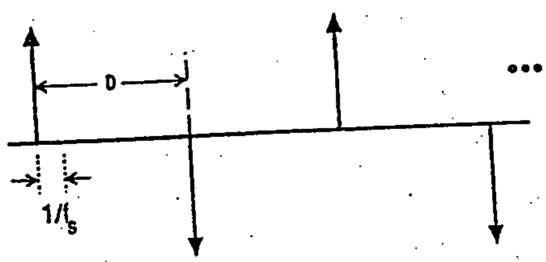


Fig. 5A

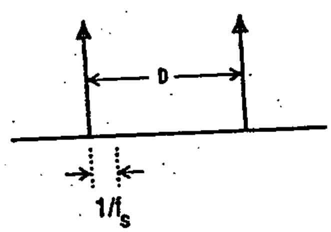


Fig. 5B

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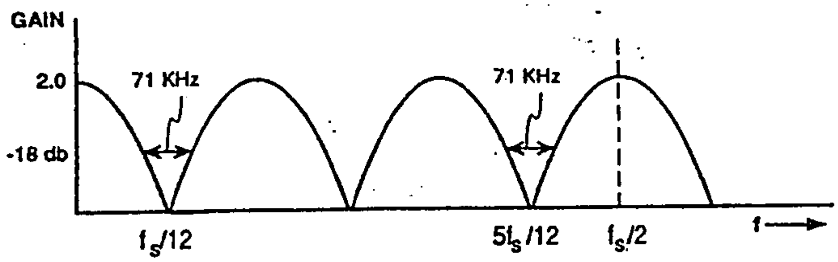


*Fig. 6*

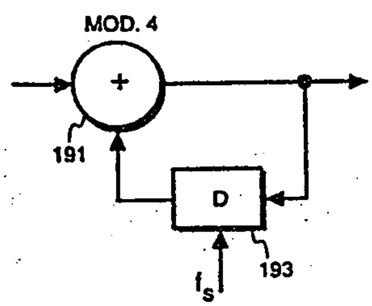


*Fig. 7A*

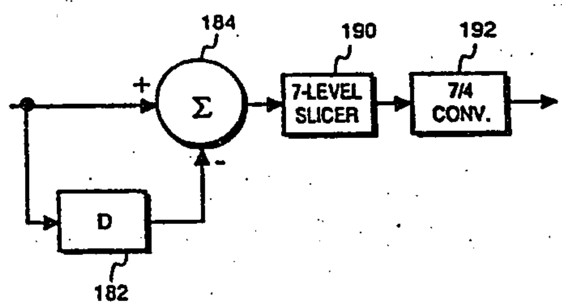


*Fig. 7B*

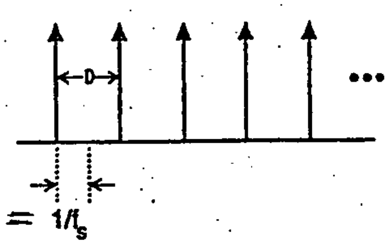


*Fig. 8A*

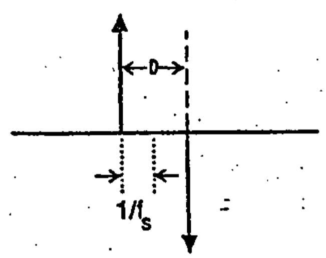


*Fig. 8B*

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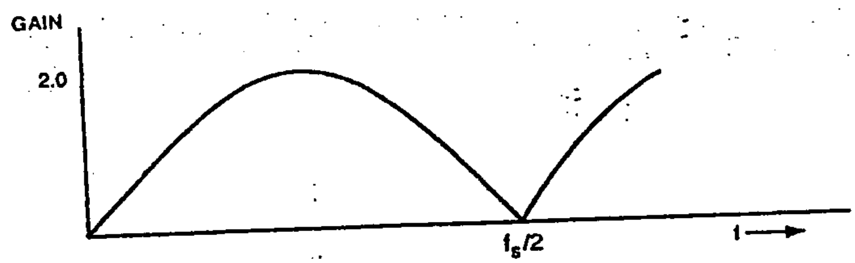


*Fig. 9*

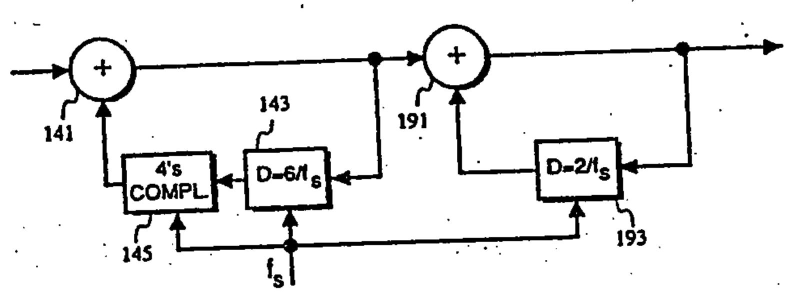


*Fig. 10A*

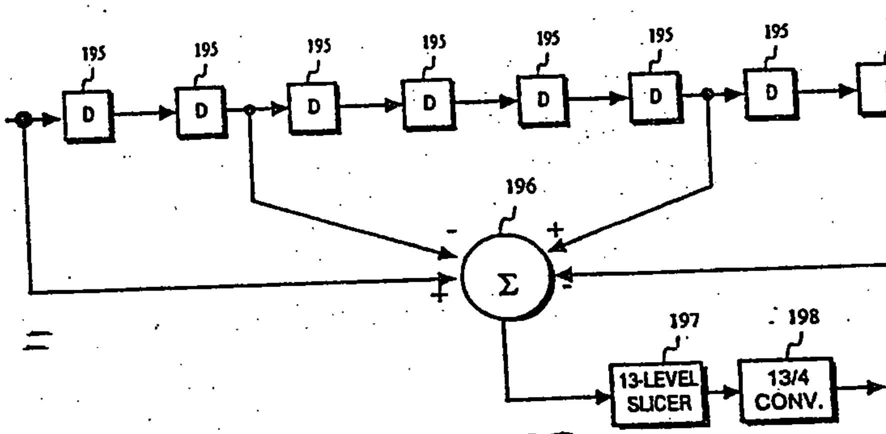


*Fig. 10B*

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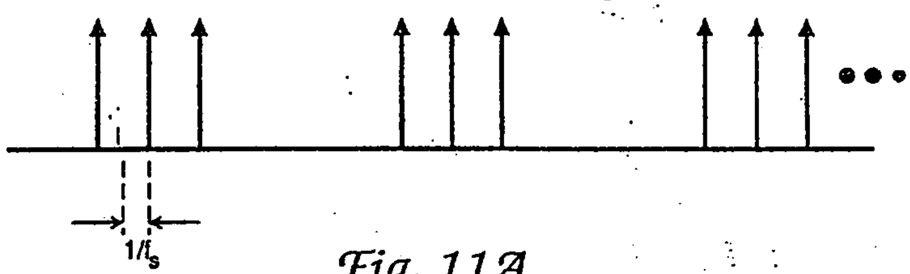


*Fig. 11A*

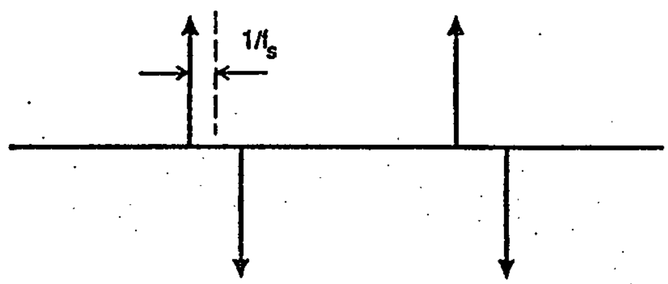


*Fig. 11B*

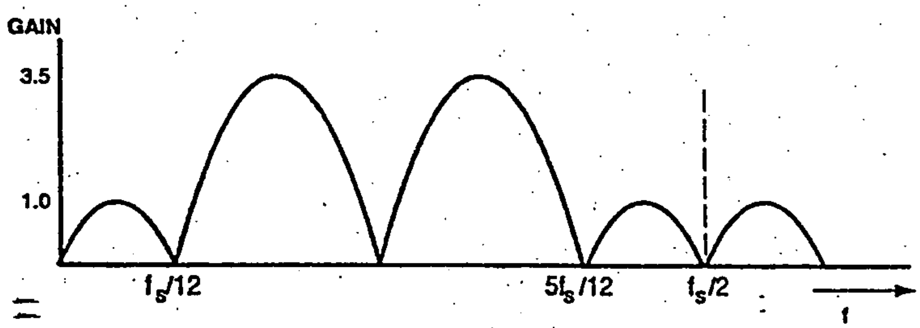


*Fig.12*

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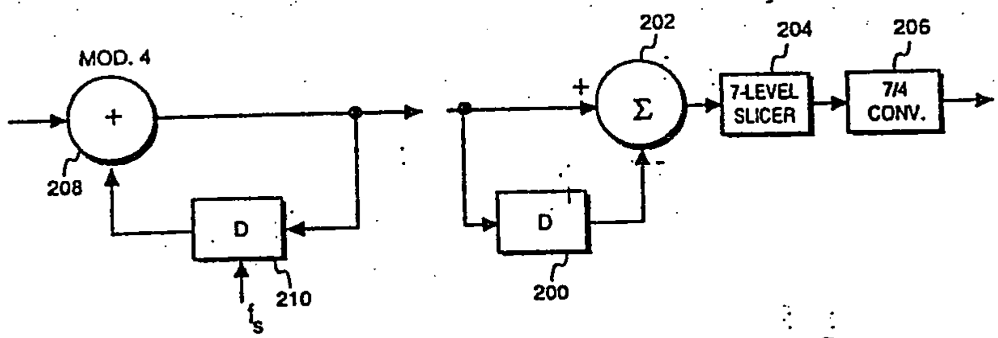


Fig. 13A

Fig. 13B

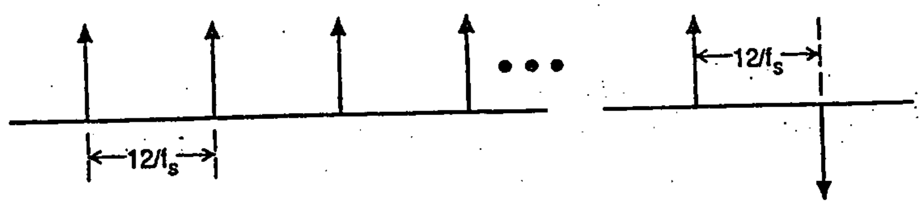


Fig. 14A

Fig. 14B

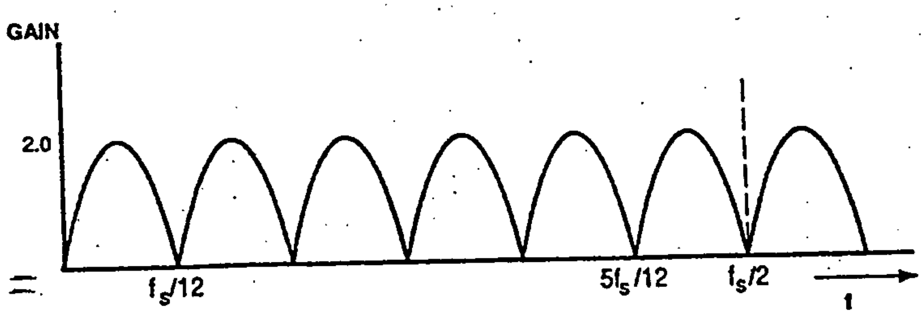


Fig.15

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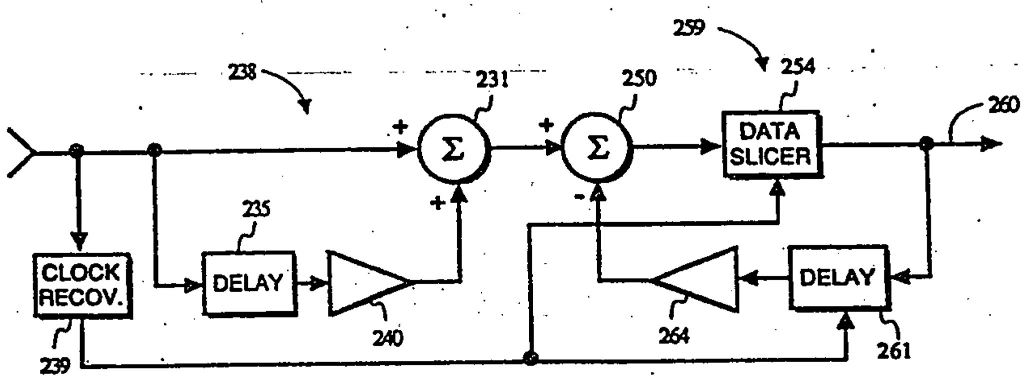


*Fig. 16*



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## ABSTRACT OF THE DISCLOSURE

A television signal transmission signal comprises a suppressed carrier, VSB signal having respective Nyquist slopes at the lower and upper edges of a 6MHz television channel, the center frequency of the Nyquist slope at the lower edge of the channel being substantially coincident with the frequency of the suppressed carrier, and the pilot signal in quadrature relation with the suppressed carrier. The suppressed carrier is modulated by an N-level digitally encoded signal having a sample rate fs substantially equal to three times the NTSC color subcarrier frequency, with the frequency of the color subcarrier being less than the co-channel NTSC picture carrier by an amount equal to about fs/12. The received signal is demodulated by a synchronous detector in response to the received pilot signal and interfering NTSC beat components are attenuated by a linear filter having notches at fs/12, 5fs/12 and fs/2. The output of the filter comprises an M-level signal, where M = greater than N, which is converted to a N-level output signal representing the televised image.

# VSB HDTV TRANSMISSION SYSTEM WITH REDUCED NTSC CO-CHANNEL INTERFERENCE

The present invention generally relates to television signal transmission systems and particularly concerns a vestigial sideband (VSB) digital television signal transmission system having reduced susceptibility to NTSC co-channel interference.

The National Television Standards Committee is an industry group that defines how television signals are encoded and transmitted in the U.S.

Simulcast broadcasting is a technique which has been proposed for providing high definition television services without obsoleting the large installed base of NTSC receivers. Simply put, simulcast broadcasting contemplates simultaneous transmission of identical program material encoded in two different formats over respective 6MHz television channels. Thus, for example, a particular program may be encoded in NTSC format for transmission over a first 6MHz television channel and in an HDTV format for transmission over a second different 6MHz television channel. Viewers equipped only with NTSC receivers would therefore be able to receive and reproduce the program encoded in NTSC format by tuning the first channel, while viewers equipped with HDTV receivers would be able to receive and reproduce the same program encoded in HDTV format by tuning the second channel.

The foregoing, of course, contemplates the allocation of additional 6MHz television channels for the transmission of HDTV encoded signals within a given NTSC

service area. While such additional channels are generally available for this purpose, at least some of the same channels are also quite likely to be allocated for NTSC transmissions in nearby television service areas. This raises the problem of co-channel interference where HDTV and NTSC transmissions over the same channel in nearby television service areas interfere with one another. NTSC co-channel interference into a received HDTV signal is of particular concern due to the relatively large picture and color carriers characterizing an NTSC transmission. HDTV systems employing an all digital transmission standard further add to this concern, since excessive NTSC co-channel interference from a nearby transmitter could abruptly render an HDTV receiver incapable of reproducing any image rather than gradually degrading the performance of the receiver.

A number of proposed HDTV systems contemplate a transmission standard comprising a pair of amplitude modulated, double sideband components having respective suppressed quadrature carriers located in the middle of a 6MHz television channel. While this transmission standard has certain desirable attributes, it also has a number of disadvantages. First and foremost, cross talk between the two quadrature channels can significantly degrade receiver performance unless special care is taken to avoid or compensate for the causes of such cross talk. Other forms of transmission standards, e.g. VSB transmission, are not subject to the cross talk disadvantage and are equally desirable in other respects,

especially where the transmission is effected in a digital format. The problem of NTSC co-channel interference, however, remains an important consideration before such a transmission standard can be successfully employed.

Accordingly the invention provides a method of providing a transmission signal for transmission over a selected channel comprising providing an N-level digitally encoded signal at a sample rate fs; and modulating a carrier signal with said N-level digitally encoded signal for forming a suppressed carrier VSB transmission signal wherein said transmission signal has a Nyquist bandwidth of fs/2, said carrier signal having a frequency below the picture and color subcarrier frequencies (fpix) and (fcs) of an NTSC co-channel signal of said selected channel by respective first and second predetermined frequencies; said VSB signal having respective Nyquist slopes at the lower and upper edges of said selected channel, the center frequency of the Nyquist slope at the lower edge of said selected channel being substantially coincident with the frequency (fc) of said carrier signal and the center frequency of the Nyquist slope at the upper edge of said selected channel being substantially coincident with the frequency (fc) of said carrier signal plus fs/2.

These and other features and advantages of the invention will be apparent upon reading the following description in conjunction with the drawings, in which:

Fig. 1 is a block diagram of a television signal transmission system constructed in accordance with the

invention;

Fig. 2 is a graph illustrating the spectrum of a 6MHz HDTV television channel in accordance with the invention.

Fig. 3 is a graph illustrating the response of an HDTV receiver of the invention to co-channel HDTV and NTSC transmission;

Figs. 4A and 4B are block diagrams of complimentary circuits which may be used in the transmitter and receiver respectively of Fig. 1 in accordance with the invention;

Figs. 5A and 5B depict the impulse response characteristics of the circuits shown in Figs. 4A and 4B respectively;

Fig. 6 is a graph illustrating the frequency domain response of the circuit shown in Fig. 4B;

Figs. 7A and 7B are block diagrams of additional complimentary circuits which may be used in the transmitter and receiver respectively of Fig. 1 in accordance with the invention;

Figs. 8A and 8B depict the impulse response characteristics of the circuits shown in Figs. 7A and 7B respectively;

Fig. 9 is a graph illustrating the frequency domain response of the circuit shown in Fig. 8B;

Figs. 10A and 10B are block diagrams of composite

circuits which combine the functions of the circuits of Figs. 4A, 7A and Figs. 4B, 7B respectively;

Figs. 11A and 11B depict the impulse response characteristics of the circuits shown in Figs. 10A and 10B respectively;

Fig. 12 is a graph illustrating the frequency domain response of the circuit shown in Fig. 11B.

Fig. 13A and 13B are block diagrams of a further complimentary circuit pair which may be used in the transmitter and receiver respectively of Fig. 1 in accordance with the invention;

Fig. 14A and 14B depicts the impulse response characteristics of the circuits shown in Figs. 13A and 13B respectively;

Fig. 15 is a graph illustrating the frequency domain response of the circuit shown in Fig. 13B; and;

Fig. 16 is a block diagram of a co-channel interference filter which may be incorporated in the receiver of Fig. 1.

The problem addressed by the present invention is generally illustrated in the block diagram of Fig. 1. An HDTV transmitter, designated generally by reference numeral 10, broadcasts an HDTV encoded signal over a selected 6MHz television channel for reception and reproduction by a corresponding HDTV receiver 100 tuned to the selected channel. At the same time, an NTSC transmitter 200 broadcasts an NTSC encoded signal over the same channel in a nearby television service area. Depending on various factors including its physical location, the HDTV receiver 100 may thus receive an undesired interfering component of considerable strength from the NTSC transmitter 200 in addition to the desired signal from HDTV transmitter 10. Since the undesired interfering signal is transmitted on the same channel as the desired HDTV signal, it is commonly referred to as co-channel interference. The co-channel interfering

signal in the HDTV receiver especially poses a problem in the case where an all digital HDTV transmission standard is employed. In particular, if the co-channel interfering signal is of sufficient strength to "swamp out" the digital HDTV signal in the receiver, the ability of the receiver to reproduce an image of any quality may be completely compromised. Moreover, this impairment of the HDTV receiver may arise quite abruptly with variations in the strength of the interfering NTSC co-channel signal. This is in contrast to analog HDTV transmission systems in which variations in the strength of the interfering NTSC co-channel signal cause gradual changes in the signal-to-noise performance of the receiver.

As is well known in the art, the spectrum of the interfering NTSC co-channel signal occupies a 6 MHz television channel and includes a luma component, a chroma component and an audio component. The luma component has a bandwidth of about 4MHz and is modulated on a picture carrier spaced 1.25MHz from one end of the channel. The chroma component, which has a bandwidth of about 1MHz, is modulated on a subcarrier spaced about 3.58MHz from the picture carrier. The audio component is modulated on a carrier spaced 0.25MHz from the other end of the channel (i.e. 4.5MHz from the picture carrier). The major contributors to co-channel interference are the relatively large NTSC picture carrier and chroma subcarrier, and to a lesser extent the audio carrier.

Fig. 2 illustrates the spectrum of an HDTV transmission channel according to the present invention. The channel occupies 6 MHz corresponding to an NTSC transmission channel through which a VSB signal is transmitted as illustrated. More particularly, a respective Nyquist slope 12 is provided at each edge of the channel with a substantially flat response portion 14 extending thereb tween. The interval between the center frequencies 16 of th respective Nyquist slopes 12 define

the Nyquist bandwidth of the channel which can be expressed as fs/2, where fs is the sampling rate of the data to be transmitted through the channel. A suppressed picture carrier fc for the channel is selected to have a frequency corresponding to the center frequency 16 of the Nyquist slope 12 at the lower edge of the channel, which therefore comprises a vestigial sideband portion including the frequencies along Nyquist slope 12 at the lower edge of the channel and a single sideband portion including the remaining frequencies up to the upper edge of the channel. It will be appreciated that modulation of the picture carrier fc results in quadrature components at all frequencies except the frequency of the picture carrier itself. This allows a quadrature pilot fp to be inserted in the channel at the frequency of the picture carrier fc to facilitate its regeneration at the receiver without interference from quadrature components resulting from modulation of the picture carrier.

In accordance with the invention, the Nyquist bandwidth fs/2 of the channel can be thought of as being divided into six (6) equal parts. The interval between the co-channel NTSC picture carrier fpix and color subcarrier fcs, taken in relation to the picture carrier frequency fpix, is defined as comprising four (4) of the six (6) parts, such that fcs = (4/6) fs/2. Therefore, fcs = fs/3 or, stated otherwise, the sampling rate fs = 3 fcs, which equals approximately 10.762 MHz. Furthermore, in accordance with the foregoing the interval between the picture carrier fc and the co-channel NTSC picture carrier fpix comprises fs/12 and the interval between the center frequency 16 of the Nyquist slope 12 at the upper edge of the channel and the co-channel NTSC color subcarrier fcs likewise equals fs/12. The intervals from the center frequencies 16 of the Nyquist slopes 12 to the respective channel edges thus comprise approximately 309.5 KHz.

Fig. 3 depicts the baseband response of HDTV receiver 100. As illustrated in this figure, the nominal

response of the HDTV receiver is substantially flat across the channel as represented by curve 20, and is characterized by a Nyquist bandwidth of fs/2. The baseband HDTV signal is preferably produced by a synchronous detector in response to a regenerated carrier having a frequency and phase corresponding to the suppressed HDTV carrier fc. In the presence of an NTSC co-channel signal, detection in response to the regenerated carrier will also provide a pair of interfering beat signals at frequencies corresponding to fs/12 and 5fs/12. In particular, a first interfering beat signal will be produced at a frequency corresponding to fs/12 in response to the regenerated carrier and the NTSC picture carrier and a second beat signal will be produced at a frequency corresponding to 5fs/12 in response to the regenerated carrier and the NTSC chroma subcarrier. The interfering beat signals are represented in Fig. 3 by reference numerals 22 and 24 respectively. As will be explained in further detail hereinafter, receiver 100 includes a filter having a response including respective notches at these two beat frequencies, as represented by reference numeral 26, for reducing the effect of the co-channel interference beats.

It may be desirable to lock the data sampling rate fs to a multiple of the horizontal scanning rate fh of the NTSC transmission to, for example, facilitate conversion between NTSC and HDTV encoded signals. Relating the nominal video sampling rate fs to the NTSC horizontal scanning rate fh provides:

$$fs = 3fcs = 3(455fh/2) = 682.5fh$$

Therefore, in order to establish an integral relation between, fs and fh, fs can be selected to equal a multiple of fh betw en, for example, 680 and 684. In a presently preferred embodiment of the invention, the sampling rate fs has been selected to equal 684 fh. In any case, the notches of response 26 will slightly deviate

from their nominal frequencies, but this can be at least partially offset by slightly shifting the HDTV RF channel so that the NTSC interference beats more closely coincide with the deviated notches. For example, this may be achieved in the case where the video sampling rate fs is selected to be 684fh by shifting the RF channel by about 38 KHz toward its lower edge. It may also be desirable to further slightly shift the RF channel for setting the picture carrier frequency fc equal to an integer multiple of one-half the NTSC horizontal line rate to, for example, facilitate the use of a line comb to recover certain components of the HDTV signal, such as a sync component.

In accordance with the foregoing, and referring back to Fig. 1, the HDTV transmitter 10 comprises a video source 30 receiving a clock signal fs from a clock generator 31 to provide a digital video signal having a bandwidth of up to about 37 MHz at a data sampling rate of fs, where fs is nominally equal to 3 fcs. As explained previously, the sampling rate may have an integral relation to the NTSC horizontal rate fh, for example, fs = 684fh. Although not limited thereto, the video signal provided by source 30 preferably comprises 787.5 progressively scanned lines per frame, 720 of which represent active video, having a vertical repetition rate corresponding to the NTSC field rate and a horizontal repetition rate corresponding to three times the NTSC horizontal scanning rate. The video signal developed by source 30 is applied to a video compressor 32 which compresses the 37MHz video signal sufficiently to allow for its transmission through a standard 6MHz television channel. The compressed video signal is then coupled to a precoder 34, which will be described in further detail hereinafter, and therefrom to a VSB modulator 36 for transmission. Both compressor 32 and precoder 34 are operated in response to clock signal fs from clock generator 31. Modulator 36 is supplied with a carrier

signal having a nominal frequency of fs/12 less than the corresponding NTSC picture carrier frequency. Also, a quadrature component of the carrier signal is applied to modulator 36 to facilitate generation of the quadrature pilot signal fp. The frequencies of the clock and carrier signals can, of course, be slightly adjusted from the nominal values as previously described. The video signal is transmitted as a sequence of N-level data samples, with the transmission preferably being effected by modulator 36 in the form of a suppressed carrier, VSB signal as illustrated in Figure 2, with the quadrature pilot signal fp being provided to facilitate regeneration of the carrier in receiver 100.

Receiver 100 includes a tuner and IF stage 110 tuned to the 6MHz television channel over which the HDTV signal is transmitted. The tuned HDTV signal, together with a co-channel NTSC signal broadcast on the same channel by transmitter 200 in a nearby television service area, are converted to an IF frequency in stage 110 and coupled to the input of a synchronous detector 120. The output of stage 110 is also coupled to a carrier regenerator 130 which is responsive to the received pilot signal for regenerating a signal having a frequency equal to but in quadrature with the HDTV suppressed carrier fc. Carrier regenerator 130 preferably comprises a narrow band frequency and phase locked loop circuit. The regenerated carrier is applied to a 90° phase shift circuit 132 and therefrom to a second input of synchronous detector 120. The output of synchronous detector 120, which is represented by the response curves of Fig. 3, thus includes the desired HDTV component, represented by curve 20, and the undesired NTSC co-channel picture and chroma beat components represented by signals 22 and 24 resp ctively. As described previously, the beat components occur at frequencies substantially corresponding to fs/12 and 5fs/12 and are produced as a

result of beating the regenerated HDTV carrier with the NTSC picture carrier and the NTSC chroma subcarrier respectively.

The output of synchronous detector 120 is coupled to a clock circuit 122 which regenerates clock signal fs and to the input of a filter and decoder stage 140. Stage 140 comprises a linear filter having a response represented by curve 26 of Fig. 3. This response includes a null at frequencies corresponding to both fs/12 and 5fs/12 to cancel or substantially cancel both the interfering NTSC picture and chroma beats. As explained in United States Patent 5,086,340, while a linear filter may be provided for producing nulls to reduce interfering NTSC co-channel signals in an HDTV receiver, it may also introduce intersymbol interference in the received HDTV digitally encoded data. This problem may be avoided by the use of precoder 34 in the HDTV transmitter to condition the compressed digital HDTV signal as fully explained in the aforesaid U.S. patent.

An exemplary precoder circuit and a complimentary linear filter, preferably comprising a comb filter, are illustrated in Figs. 4A and 4B respectively. The comb filter comprises a feedforward circuit coupling the output of synchronous detector 120 to the input of a delay circuit 142 and to one input of a summer 144. The output of delay circuit 142 is coupled to a second input of summer 144. Summer 144 adds the delayed signal to the undelayed signal and, assuming the use of a four level digitally encoded signal, couples the result to a 7-level slicer 146. The output of slicer 146 is coupled to a 7-level to 4-level converter 148 which maps the seven level output of slicer 146 to a four level output corresponding to the digitally encoded signal produced at the output f compressor 32 f transmitter 10. The impulse response of the comb filter is illustrated in Fig.

5B. The complimentary precoder of Fig. 4A comprises a feedback circuit comprising a modulo-4 adder 141 receiving the output of compressor 32 at a first input. The output of adder 141 is fed back through a delay 143 and a 4's compliment circuit 145 to a second input of adder 141. The feedback signal is therefore effectively subtracted from the input signal. The impulse response of the precoder is illustrated in Fig. 5A. As fully explained in the previously mentioned United States Patent 5,086,340, the use of the precoder in transmitter 10 facilitates the use of 7-level slicer 146 and 7-level to 4-level converter 148 for eliminating the intersymbol interference introduced in the received HDTV digital data samples by the comb filter in receiver 100.

In order to provide the desired complimentary operation of the precoder and comb filter illustrated in Figs. 4A and 4B, the delays characterizing delay circuits 142 and 143 must be identical. Moreover, the delay characterizing the precoder must be an integral multiple of the data sampling rate fs, i.e. D=N (1/fs), since the precoder 141 performs a purely digital operation. As a consequence, the delay characterizing delay circuit 142 of the comb filter must also be D=N (1/fs). The frequency response of the comb filter of Fig. 4B with N set equal to 6 is illustrated in Fig. 6 and will be seen to include notches at both desired frequencies fs/12 and 5fs/12. At the -18db point each notch has a width of about 75 KHz.

An additional complimentary precoder -filter pair may be provided for reducing the beat signal occurring near fs/2 caused by the NTSC co-channel audio carrier as illustrated in Figs. 7A and 7B respectively. The impulse responses of these circuits are shown in Figs. 8A and 8B respectively. The comb filter of Fig. 7B also comprises a feedforward circuit whose input is coupled to the input of a d lay circuit 182 and to one input of a summer 184. The output of delay circuit 182 is coupled to the negative

input of summer 184 so that the delayed signal is subtracted from the input signal. Delay circuit 182 is characterized by a delay corresponding to 2/fs. Summer 184 provides an output to a 7-level slicer 190, the output of which is then applied to a 7-level to 4-level converter 192 which maps the 7-level output of slicer 190 to a 4-level output. The frequency response of the comb filter of Fig. 7B is illustrated in Fig. 9 and will be seen to include a notch at fs/2 as desired for attenuating the NTSC co-channel audio beat.

The complimentary precoder circuit of Fig. 7A comprises a feedback circuit comprising a modulo-4 adder 191 receiving the output of compressor 32 at a first input. The output of adder 191 is fed back through a delay circuit 193 characterized by a delay corresponding to 2/fs. The output of delay circuit 193 is applied to the second input of adder 191 which therefore effectively adds the feedback signal to the input signal to produce the impulse response shown in Fig. 8A.

The comb filters of Figs. 4B and 7B may be connected in series to effect attenuation of the NTSC co-channel picture carrier and color subcarrier beats as well as the NTSC co-channel audio carrier beat. Alternatively, the impulse responses of the two comb filters may be convolved to derive a composite impulse response from which a composite filter may be synthesized. This is illustrated in Figs. 10-12. In particular, Fig. 10A illustrates a precoder comprising the precoders of Figs. 4A and 7A connected in series, the impulse response of which is shown in Fig. 11A, while Fig. 10B illustrates a complimentary comb filter circuit synthesized on the basis of the convolved impulse response shown in Fig. 11B.

The comb filter of Fig. 10B comprises eight 1/fs delay elements 195 connected in series. The input signal from detector 120 is applied to the first delay element

195 and to a positive input of a summer 196. The outputs of the second and eighth delay elements 195 are applied to respective negative inputs of summer 196 and the output of the sixth delay element 195 is applied to a positive input of summer 196. The frequency response of the filter is illustrated in Fig. 12 and will be seen to comprise notches at all three beat frequencies, fs/12, 5fs/12 and fs/2, as desired. The output of summer 196 is coupled to a 13 - level slicer 197 and therefrom to a 13/4 converter 198.

Alternatively, the complimentary precoder-filter pair illustrated in Figs. 13A and 13B respectively may be used to attenuate the NTSC picture carrier, color subcarrier and audio carrier beats occurring at frequencies corresponding to about fs/12, 5fs/12 and fs/2 respectively. The impulse responses of these circuits are shown in Figs. 14A and 14B respectively. The filter of Fig. 13B comprises a feedforward circuit whose input is coupled to the input of a delay circuit 200 and to one input of a summer 202. The output of delay circuit 200 is coupled to the negative input of summer 202 so that the delayed signal is subtracted from the input signal. Delay circuit 200 is characterized by a delay corresponding to 12/fs. Summer 202 provides an output to a 7-level slicer 204, the output of which is applied to a 7-level to 4-level converter 206 which maps the 7-level output of slicer 204 to a 4 level output. The frequency response of the filter of Fig. 13B is illustrated in Fig. 15 and will be seen to include notches at fs/12, 5fs/12 and fs/2 for attenuating the NTSC co-channel beat signals.

The complimentary precoder of Fig. 13A comprises a feedback circuit comprising a modulo-4 adder 208 receiving the output of compressor 32 at a first input. The output of adder 208 is fed back through a delay circuit 210 characterized by a d lay corresponding to 12/fs. The output of delay circuit 210 is applied to the

second input of adder 208 which therefore effectively adds the feedback signal from delay circuit 210 to the input signal to produce the impulse response shown in Fig. 14A.

In the absence of co-channel interference from an NTSC transmitter, a complimentary feed-forward decoder can be used in any of the embodiments of Figs. 4B, 7B, 10B and 13B to decode the precoded signal as explained in the aforesaid U. S. application. This avoids the noise degradation introduced by the comb filters.

Finally, referring back to Fig. 1, the output of the comb filter and decoder 140 is coupled to an expansion circuit 150 for reconstructing a wideband video signal representing the original 37 MHz video source signal. The reconstructed signal is applied to a display 160 for displaying the reconstructed image.

In the alternative, filter and decoder 140 may be implemented in the form illustrated in Fig. 16. In this case, the use of precoder 34 in transmitter 10 is not required. Referring to Fig. 16, the filter arrangement comprises a series combination of a comb filter 238 and an intersymbol interference filter 259. Comb filter 238 is operative to reduce co-channel interference at its input but also produces an undesired intersymbol interference signal. Intersymbol interference filter 259 is operative to remove this intersymbol interference signal.

More specifically, comb filter 238 includes a summer network 231 having a first positive input coupled for receiving the data from detector 120 and a second positive input for receiving the data through a delay network 235 and an amplifier 240. Delay 235 is preferably selected to produce a signal delay precisely equal to a selected NTSC periodicity characteristic and the gain of amplifier 240 is chosen to produce a feed forward gain of less than one. Intersymbol interference filter 259 includes a summ r 250 having a positive input coupled to receive the output of summer 231, a negative input and an

output. A data slicer 254 has an input coupled to the output of summer 250 and an output coupled to a data output terminal 260. The output of data slicer 254 is fed back to the negative input of summer 250 through a delay 261 (providing a delay equal to that of delay 235) and an amplifier 264. Data slicer 254 and delay 261 are operated in response to a clock recovery circuit 239 which produces a clock signal that is maintained at a multiple of the selected NTSC periodicity.

In operation, comb filter 238 is characterized by a frequency response selected for reducing selected NTSC co-channel interference signals. However, as mentioned previously, filter 238 also produces an undesired intersymbol interference signal. Filter 259 is effective for removing this intersymbol interference signal by producing a negative replica thereof which is used to cancel the former signal. As a result, the overall response of filters 238 and 259 is substantially free of both NTSC co-channel interference and intersymbol interference.

It will be apparent to those skilled in the art that while the system set forth herein utilizes a four level digitally encoded signal, the present invention may be utilized in other digital systems using other digital encoding formats.

What has thus been shown is a high definition television transmission system which substantially reduces NTSC co-channel interference without significantly degrading HDTV receiver performance. The system shown is capable of application to numerous types of digital processing formats for high definition television systems.

While particular embodiments of the invention have been shown and described, it will be obvious to those skilled in the art that changes and modifications may be made without departing from the invention in its broader

aspects. Therefore, the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of the invention.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A method of providing a transmission signal for transmission over a selected channel comprising providing an N-level digitally encoded signal at a sample rate fs; and modulating a carrier signal with said N-level digitally encoded signal for forming a suppressed carrier VSB transmission signal wherein said transmission signal has a Nyquist bandwidth of fs/2, said carrier signal having a frequency below the picture and color subcarrier frequencies (fpix) and (fcs) of an NTSC co-channel signal of said selected channel by respective first and second predetermined frequencies; said VSB signal having respective Nyquist slopes at the lower and upper edges of said selected channel, the center frequency of the Nyquist slope at the lower edge of said selected channel being substantially coincident with the frequency (fc) of said carrier signal and the center frequency of the Nyquist slope at the upper edge of said selected channel being substantially coincident with the frequency (fc) of said carrier signal plus fs/2.

2. The method of claim 1, including providing a pilot signal at the frequency (fc) of said suppressed carrier.

3. The method of claim 1 or 2, wherein said sample rate fs is substantially equal to an integer multiple of the NTSC horizontal scanning frequency (fh).

4. The method of any one of claims 1, 2 and 3, wherein said selected channel is a television channel and has a bandwidth substantially equal to the bandwidth of said NTSC co-channel signal.

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5. The method of any one of claims 1 to 4, wherein said picture and color subcarrier frequencies (fpix) and (fcs) have respective frequencies substantially equal to (fc+fs/L) and (fc+fs(P/L)), where L and P are selected integers with P being less than L.

6. A receiver for receiving a signal transmitted over a selected channel comprising means for receiving a signal comprising a suppressed carrier VSB transmission signal modulated by an N-level digitally encoded signal having a sample rate fs; including said received signal having a Nyquist bandwidth of fs/2, said carrier signal having a frequency below the picture and color subcarrier frequencies (fpix) and (fcs) of an NTSC co-channel signal of said selected channel by respective first and second predetermined frequencies; said VSB signal having respective Nyquist slopes at the lower and upper edges of said selected channel, the center frequency of the Nyquist slope at the lower edge of said selected channel being substantially coincident with the frequency (fc) of said carrier signal and the center frequency of the Nyquist slope at the upper edge of said selected channel being substantially coincident with the frequency (fc) of said carrier signal plus fs/2; and demodulation means coupled to said receiving means for recovering said N-level digitally encoded signal.

7. The receiver of claim 6, wherein said selected channel is a television channel having a bandwidth substantially equal to the bandwidth of said NTSC co-channel signal.

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8. The receiver of any one of claims 6 and 7, wherein said received signal includes a pilot signal at the frequency (fc) of said carrier, and further including means responsive to the received pilot signal for regenerating a demodulation signal having a frequency corresponding to the frequency (fc) of said suppressed carrier.

9. The receiver of any one of claims 6, 7 and 8, wherein said sample rate fs is substantially equal to an integer multiple of the NTSC horizontal scanning frequency.

10. The receiver of any one of claims 6 to 9, wherein said demodulation means includes filter means (Fig. 4B, 7B, 10B, 13B, or 16) having respective filter notches at frequencies substantially equal to fpix-fc and fcs-fc for attenuating interference from said NTSC co-channel signal.

11. The receiver of claim 10, wherein said picture and color subcarrier frequencies (fpix) and (fcs) have respective frequencies substantially equal to (fc+fs/L) and (fc+fs(P/L)), where L and P are selected integers with P being less than L, and wherein said filter means notches are at respective frequencies substantially equal to (fs/L) and fs(P/L).

12. The receiver of claim 10, wherein the frequency response of said filter means includes yet a further notch at a frequency substantially equal to the difference between the frequency (fc) of said suppressed carrier and the frequency (fa) of the audio carrier of said interfering co-channel television signal.

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13. The receiver of claim 10, wherein aid filter means comprises means for developing an M-level output signal, where M is greater than N, and further including means for converting said M-level output signal to an N-level signal representing said N-level digitally encoded signal.

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